BEUV nanolithography: 6.7 or 11 nm?

N. I. Chkhalo, N. N. Salashchenko

Institute for physics of microstructures of RAS,
Nizhny Novgorod, Russia

2013 International Workshop on EUV and Soft X-Ray
Dublin · Ireland · November 3-7 · 2013

Outline

- Short introduction. Selection of the working wavelength for the (B)EUVL
- Issues of the La/B multilayer optics for BEUVL at 6.7 nm
- Multilayer Be- and Sr- based optics for BEUVL at 11 nm
- Efficiency comparison of BEUVL at 11nm and EUVL at 13.5 nm
- Suggestions for further work

N.I. Chkhalo, N.N. Salashchenko. **Next generation nanolithography based on Ru/Be and Rh/Sr multilayer optics // AIP Advances**. 2013. Vol.3, Issue 8. P. 082130.

Criteria for selection of the working wavelength for the (B)EUVL:

1. High space resolution — $res = k_1 \cdot \lambda / NA$
2. Acceptable — $dof \approx \lambda / (NA)^2$
3. High efficient radiation — source
4. Presence of sensitive — photoresist

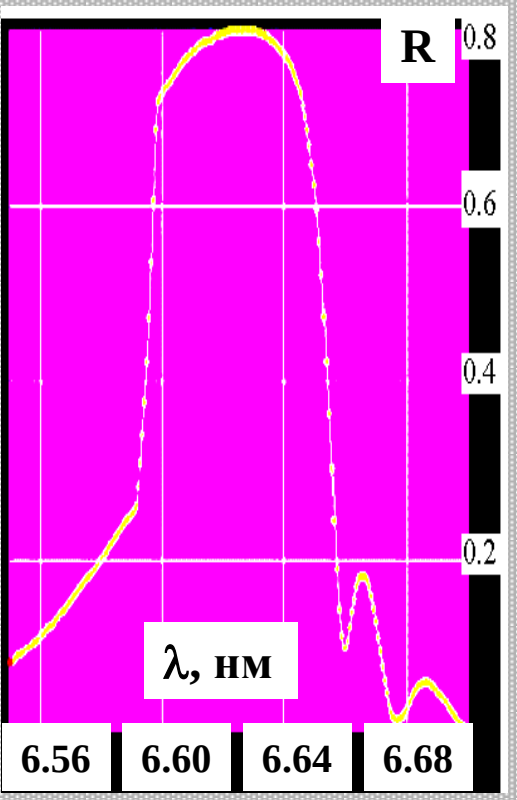
Efficiency comparison of BEUVL

$$E = R_m^{10} \cdot S(\lambda) \cdot \Delta\lambda = R_m^{10} \cdot CE$$

R_m^{10}	Reflection coefficient of 10 mirror's system
CE	Conversion efficiency in-band

- D. Glushkov, V. Banine, L. Sjmaenok, N. Salashchenko, N. Chkhalo. Multilayer mirror and lithographic apparatus. WO 10091907 A1. 19.08.2010.

Efficiency comparison of EUVL (13.5 nm) and BEUVL (6.7 nm) lithography



$$E = R_m^{10} \cdot S(\lambda) \cdot \Delta\lambda = R_m^{10} \cdot CE$$

R_m^{10} Reflection coefficient of 10 mirror's system

CE Conversion efficiency in-band

λ, nm	Ions	MLS	R_m^{10}, %	$\Delta\lambda$, nm	CE, %	E $\times 10^2$
13.5	**Sn**	**Mo/Si**	**4.4**	**0.27**	**4**	**18**
6.78	Gd	La/B	3.4	0.034	1.7	5.8
6.62	**Tb**	**La/B**	**15**	**0.045**	**1.7**	**26**

La/B

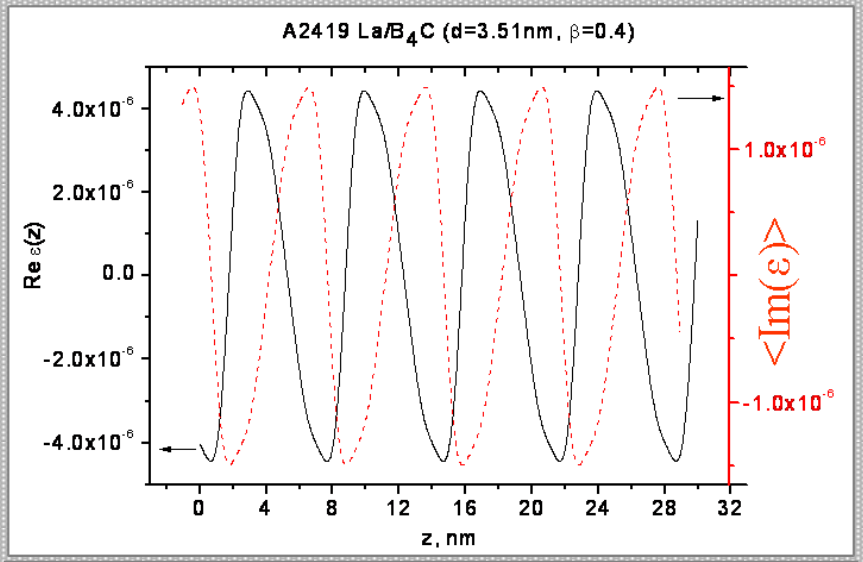
λ_{max} = 6.69 nm

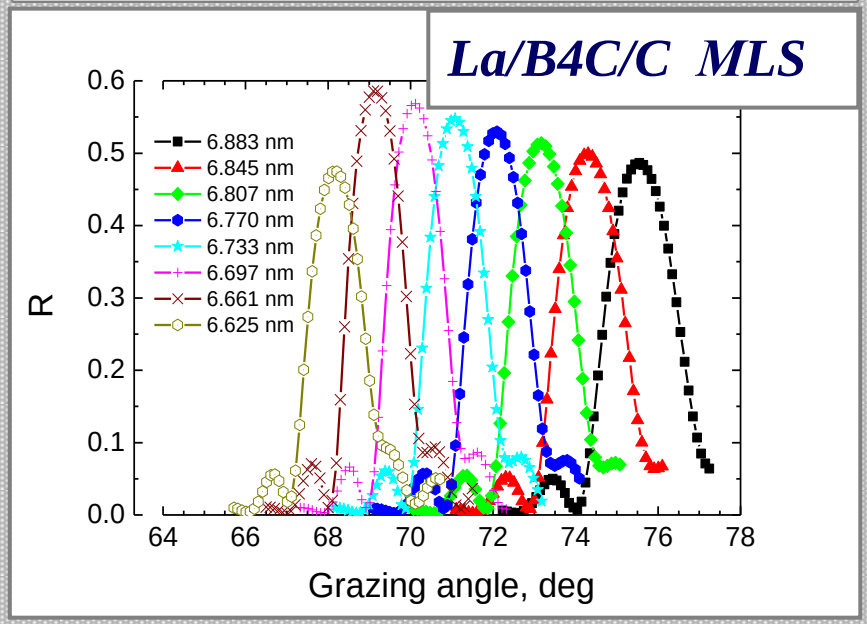
R_{max} = 80%

$\Delta\lambda$ = 0.06 nm

Theoretically productivity at 6.7 nm is higher than that at 13.5 nm!

Issues of the La/B multilayer optics for BEUVL at 6.7 nm. *Reflectivity of La/B_4C MLSs*





Interfaces are strongly asymmetric:

$\Delta_1 \approx 1.5$ nm when La→B4C and

$\Delta_2 \approx 0.5$ nm when $B_4C \rightarrow La$

$R \approx 45\text{-}48\%$

N.I. Chkhalo, S. Künstner, V.N. Polkovnikov, N.N. Salashchenko, F. Schäfers, S.D. Starikov. ***High performance La/B4C multilayer mirrors with barrier layers for the next generation lithography*** // **Appl. Phys. Lett. 2013.** V. 1020. P.011602.

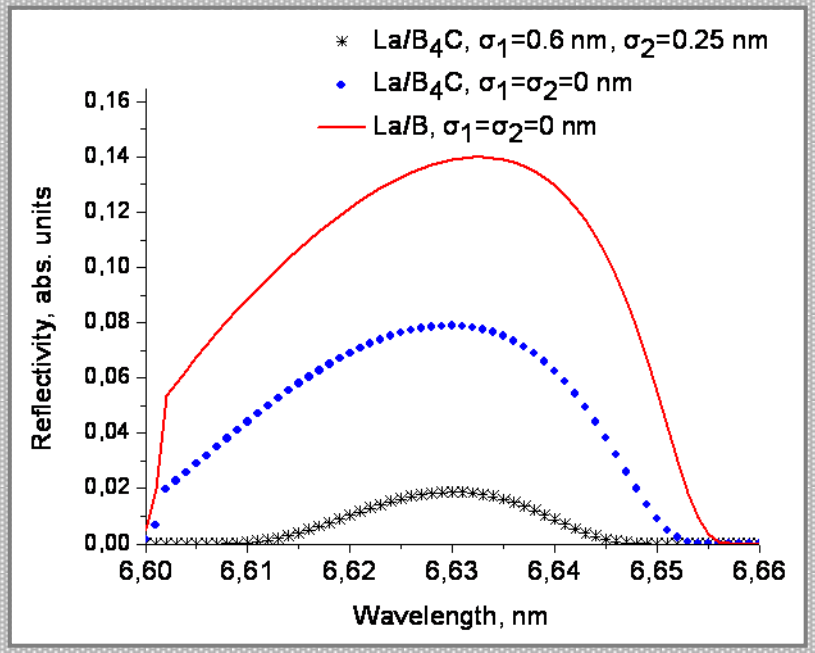
***La/B4C/C* :**

$\Delta_1 \approx 0.3$ nm when La→B4C and

$\Delta_2 \approx 0.5$ nm when $B_4C \rightarrow La$

$R \approx 58.6\%$

Issues of the La/B multilayer optics for BEUVL at 6.7 nm. *Reflectivity of La/B_4C MLSs*



The problem of increasing the reflectivity of La/B multilayer mirrors is key and defining prospects of BEUV lithography at a wavelength of 6.7 nm!!!

λ, nm	Ions	MLS	R_m^{10}, %	$\Delta\lambda$, nm	CE, %	E $\times 10^2$
6.63	**Tb**	**La/B**	**14**	**0.045**	**1.7**	**26**
6.63	**Tb**	**La/B_4C**	**1.8**	**0.021**	**0.8**	**1.4**

Reflectivity of La/B_4C MLSs. Magnetron sputtering + ion beam polishing

Ideas:

- **Smoothing the film roughness**
- **Removing porous upper layer, so reducing the interdiffusion**

Result at λ=6.70 nm :

When polishing B_4C no effect is observed

When polishing La reflectivity rise by 2%.

Conclusion on issues of the BEUVL at 6.7 nm

Problems:

- **low reflectivity of La/B Multilayer mirrors**
- **doubling the quality requirements for the optics**
- **low absorption of organic and low sensitivity non-organic resists**
- **lower, as compared with EUV, *CE* of BEUV source**

made the BEUV at 6.7 nm very CHALLENGING!

In view of the risks we do believe that, in parallel with research in the field at 6.7 nm, it is time to start looking at other spectral ranges. When choosing a new wavelength it is necessary to consider increasing both the spatial resolution and the performance of the system

Multilayer optics for the BEUVL around 11 nm

Mo/Be MLS – C. Montcalm, S. Bajt, P. Mirkarimi, E. Spiller, F. Weber, J. Folta, SPIE 3331, 42-51 (**1998**)

Reflectivity at **λ=11.34 nm R_{exp}=70.2%, $\Delta\lambda_{FWHM}$=0.27 nm** when the theoretical limit is **R_{th}=75.6%**.

$\Delta\lambda_{FWHM}$ it is **2 times smaller** in comparison with **Mo/Si**

V. Banine, J. Benschop, M. Leenders, R. Moors. **Proc. SPIE** 3997, 126 **(2000).**

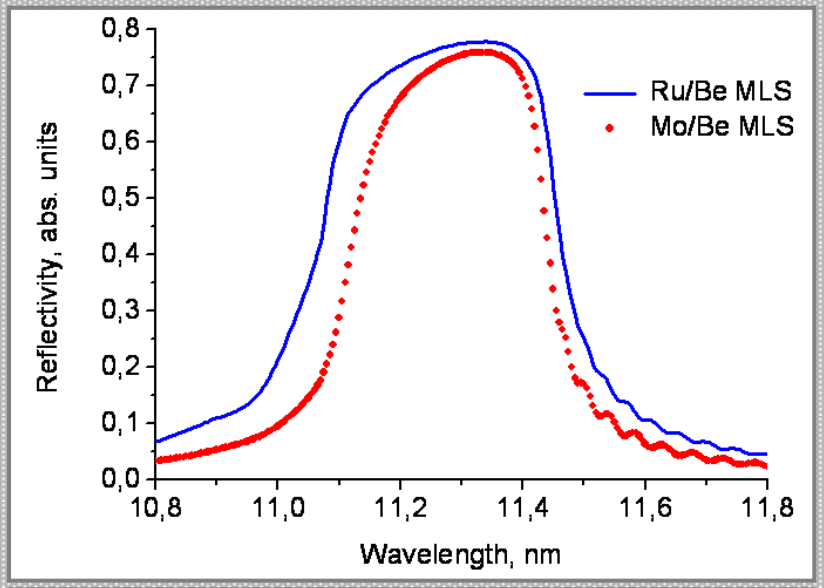
Mo/Sr MLS – B. Sae-Lao, et al., Optics Letters 26(7), 468-470 (**2001**).

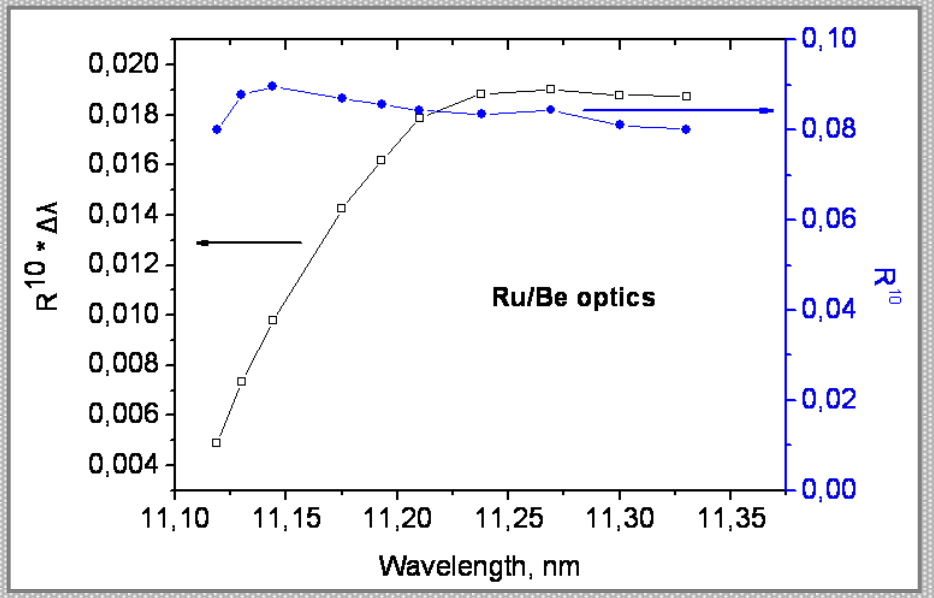
Reflectivity at **λ=10.5 nm R_{exp}=48.3%, $\Delta\lambda_{FWHM}$=0.15 nm**

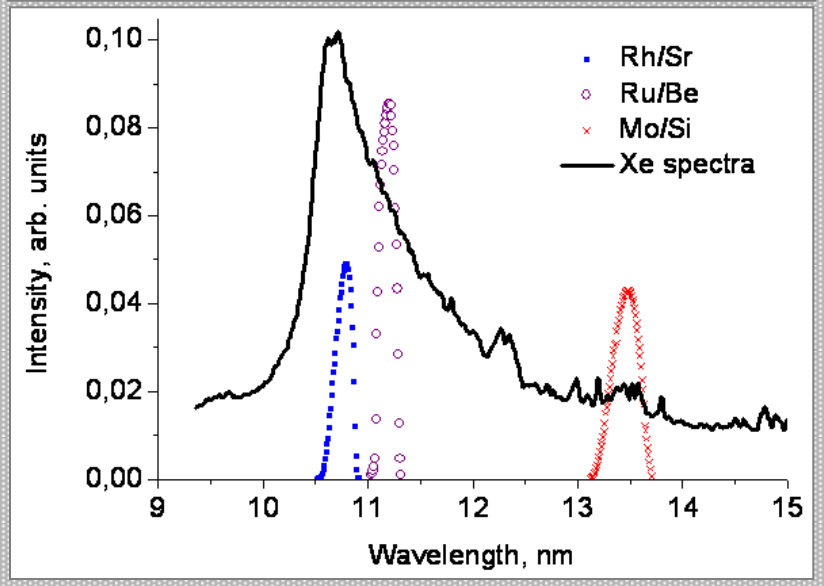
- Theoretical reflectivity less than 70%
- Strong oxidization
- Narrow band pass

Multilayer optics for the BEUVL around 11 nm

Instead of Mo/Be and Mo/Sr we propose Ru/Be and Rh/Sr MLS

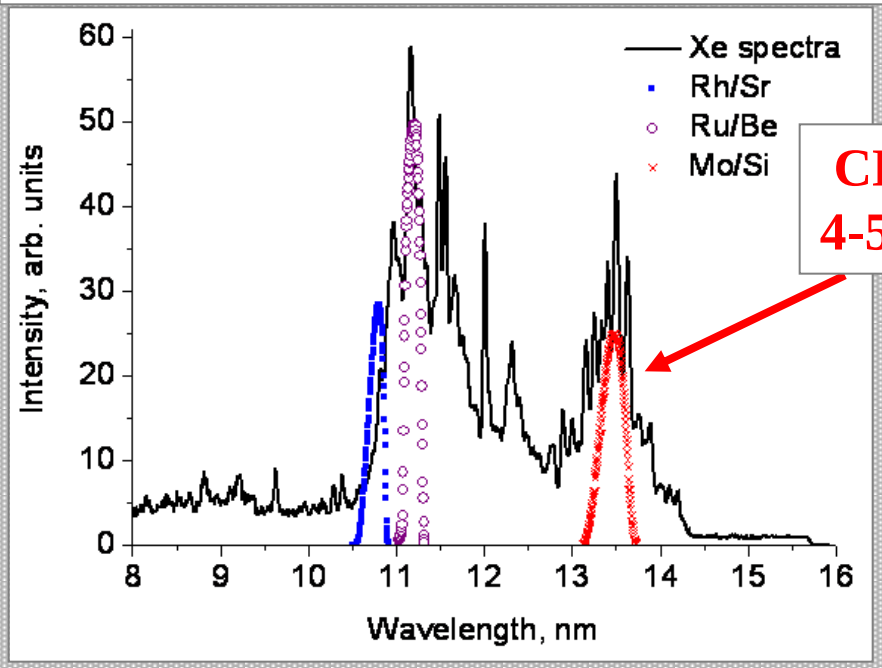




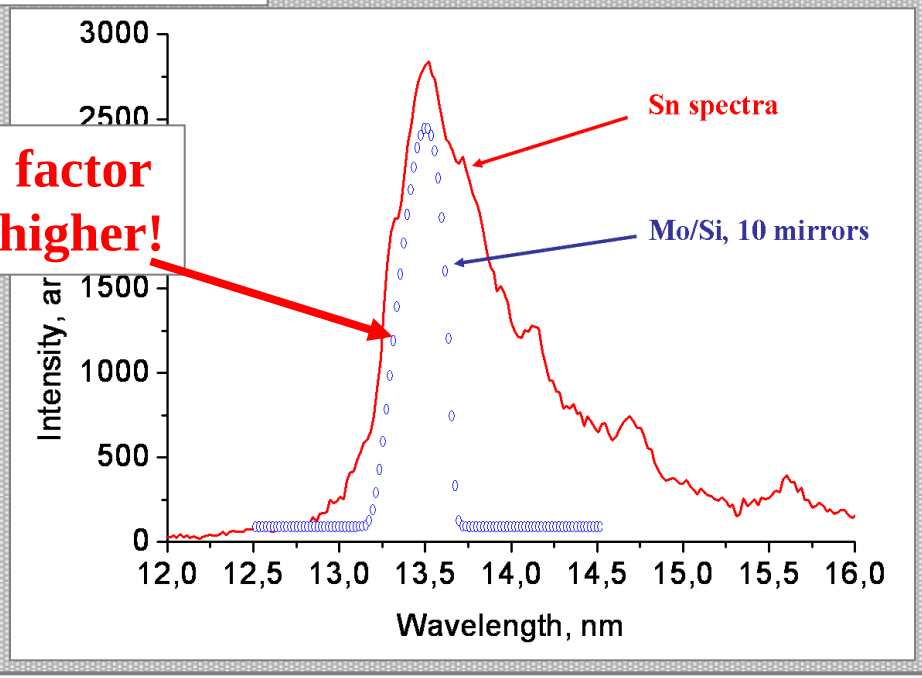


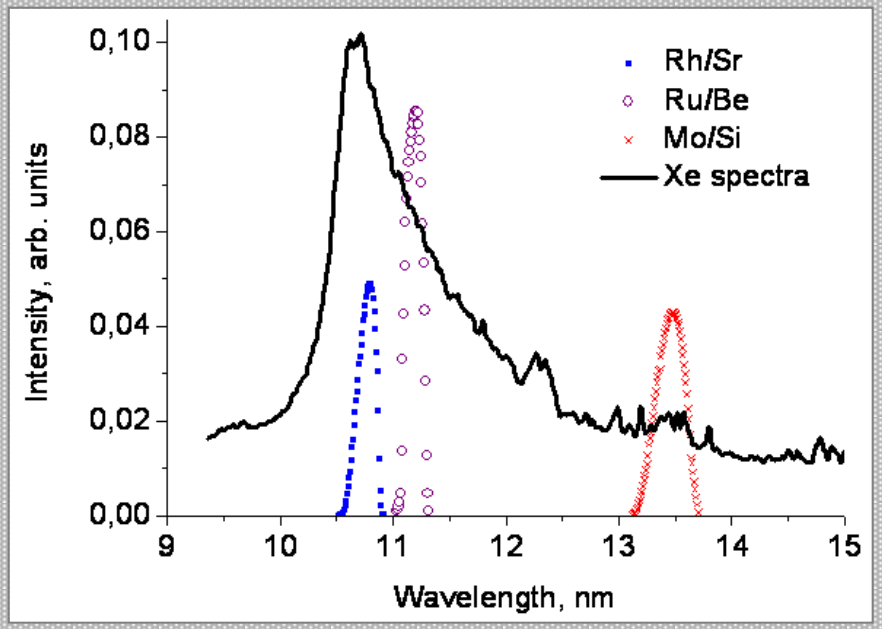
λ,nm	MLS	R_m^{10}, %	$\Delta\lambda$, nm (%)	$R_m^{10} \times \Delta\lambda$
13.5	**Mo/Si**	**4.4**	**0.27 (2%)**	**1.19**
11.2	**Ru/Be**	**8.6**	**0.19 (1.7%)**	**1.63**
10.8	**Rh/Sr**	**5.0**	**0.19 (1.8%)**	**0.95**

Source for BEUVL around 11.2nm



CE factor
4-5 higher!





CE of Sn at 13.5 nm and Xe at 11.2 nm are comparable!!!

1. V Y Banine, K N Koshelev and G.H.P.M. Swinkels. J. Phys. D: Appl. Phys. 44, 25300 (2011).
2. E.R. Kieft, K. Garloff, A.M. van der Mullen, V. Banine. Phys. Rev. E 72, 036402 (2005).

Comparison of the parameters of the optical systems and the most promising radiation sources for BEUVL

λ, nm	Ions	MLS	d, nm	R_m^{10}	$\Delta\lambda$, nm	$\Delta\lambda/\lambda$, %	CE, % (in band)	$E=R_m^{10}CE$
13.5	**Sn**	**Mo/Si**	**6.9**	**0.044**	**0.27**	**2**	**4.5**	**0.20**
11.18	**Xe**	**Ru/Be**	**5.65**	**0.086**	**0.19**	**1.7**	**3.6**	**0.31**
10.8	**Xe**	**Rh/Sr**	**5.52**	**0.050**	**0.19**	**1.8**	**3.6**	**0.18**
10.5	**Cs**	Rh/Sr	5.38	0.055	0.14	1.3	?	**?**
6.62	**Tb**	**La/B**	**3.32**	**0.15**	**0.045**	**0.6**	**1.7**	**0.255**

Advantages and Issues of the BEUV around 11 nm

Advantages

1. **~ 20% better resolution**
2. **Optics requirements are close to that for 13.5 nm**
3. **Lower debris produced by Xe source**
4. **Higher reflectivity of multilayers and filter's transmission**
5. **About factor 1.5 lower sensitivity to contamination by hydrocarbons**
6. **Incorporation into organic resist molecule about 2-3 atoms of Si leads to the same absorption like at 13.5 nm**
7. Hypothetically higher performance of the facility as compared with **13.5 nm EUVL**

Advantages and Issues of the BEUV around 11 nm

ISSUES

1. True reflection coefficients of Ru/Be MLSs around 11 nm
2. Possibility of increasing the band-path and shifting operating wavelength closely to 11 nm
3. True conversion efficiencies of Xe source in the region of 11 nm for different ion stages (matching emission and reflection band-paths)
4. Conversion efficiency of Cs source in the region of 10.5 nm

These investigations require no significant capital investment, and will give a definite answer to the question of the advisability of deploying a full-scale study into the field of BEUV lithography around 11 nm.

MANY THANKS for YOUR ATTENTION!!!